Ultrasonic Processing of Materials

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Industrial Participants

Carpenter Technologies Co.

Secat, Inc.

Project Objective

- To establish quantitative basis for nucleation, growth, and fragmentation processes during alloy solidification in an acoustic field
- To develop a better practice to produce small and non-dendritic grains during solidification
- To demonstrate that degassing in aluminum melt can be achieved using ultrasonic vibrations

Benefits

- Enhance the understanding of the application of ultrasonic power to the processing of aluminum alloys.
- Material savings in the form of reduced grain refiner additions.
- Energy savings of one trillion Btu by 2025, and concomitant environmental benefits

Funding Level

FY	OIT
2002	150K
2003	150K
2004	150K

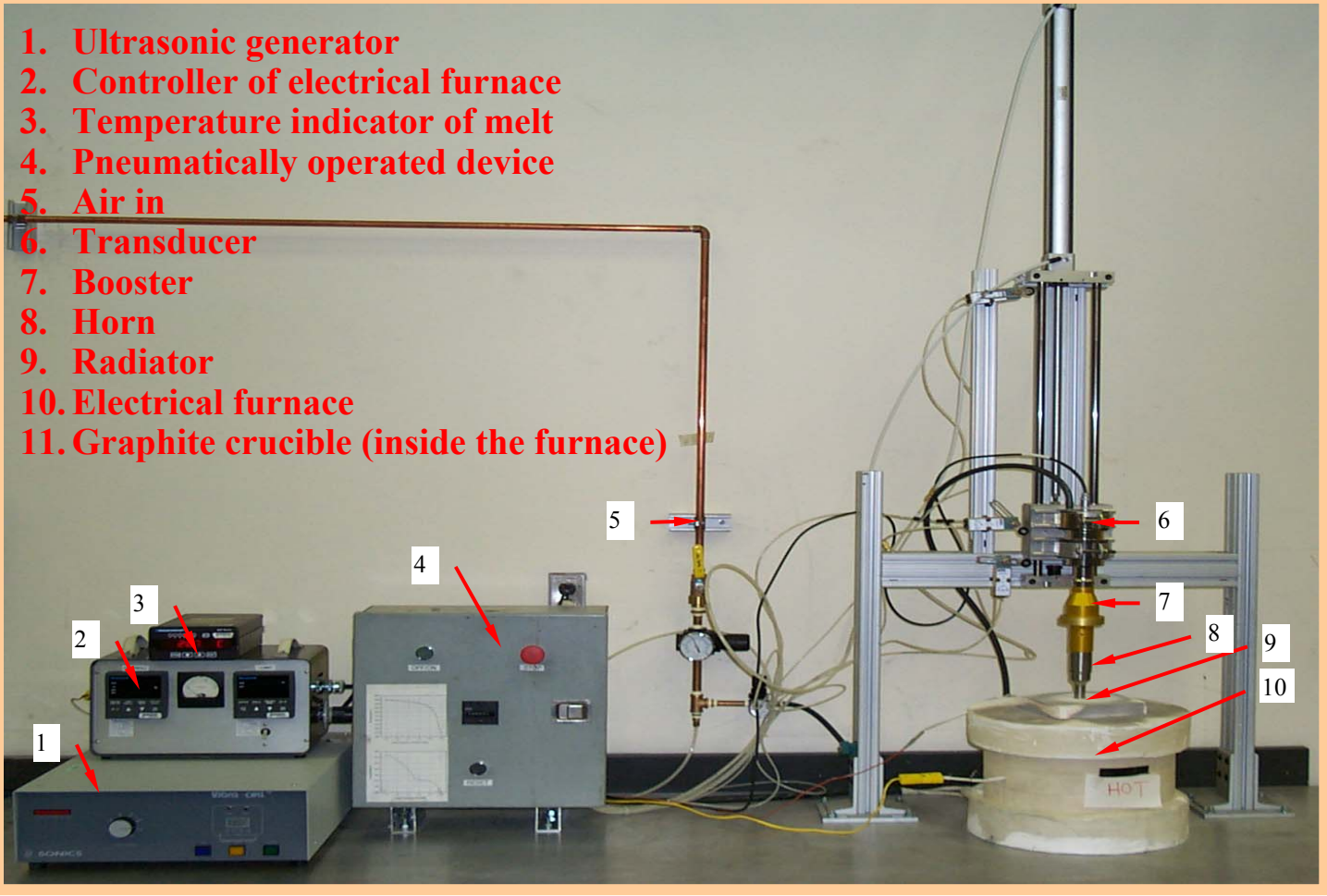
Industrial Involvement

- 1/8/03 Progress review meeting with Secat, inc. at ORNL.
- 4/16/03 Progress review meeting with Ohio Valley Aluminum, Carpenter, and Secat at Lexington.
- Received from industrial partners: 100 lbs 6061 alloy, 100lbs of aluminum 6062 alloy, and some commercial grain refiners.

Project Tasks, Milestone and Plan

ID Number	Task/Milestone Description	Planned Completion	Actual Completion	Comments
Task 1	Experimental apparatus	3/31/02	3/31/02	Completed
Task 2	Degassing Al melts	9/30/03	6/30/03	Completed
Task 3	Thermodynamic modeling	3/31/03	3/31/03	Completed
Task 4	Solidification of alloys using ultrasonic energy	9/30/04		Planned
Task 5	Characterization of solidification microstructures	9/30/04		Planned
Task 6	Determination of fundamental mechanisms	3/31/04		Planned
Task 7	Industrial applications of results	9/30/04		Planned
Task 8	Reports and publications	9/30/04		Planned

Ultrasonic Processing System



Highlight of the Ultrasonic System

- **Ultrasonic resource:**
  - Powerful acoustic energy input and frequency adjustable
    - For 20 KHz, 0~1500 Watt
    - For 100 KHz~15 MHz, 0~300 Watt
- **Other components**
  - Air cooled PZT transducer
  - Booster; probe, radiator (Ti-6Al-4V) modified for high temperature application

Radiator: Problem at High Temperatures

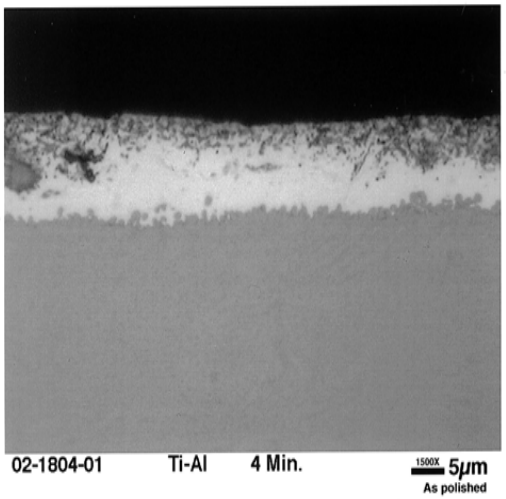
Commercial ultrasonic horn could not work at high temperatures

- The length of the radiator is a multiple of one half wavelength
- The wavelength is proportional to the ultrasound velocity
- Ultrasound velocity decreases with increasing temperature
- There is a temperature gradient in the radiator during ultrasonic processing
- The length of the radiator has to be determined experimentally

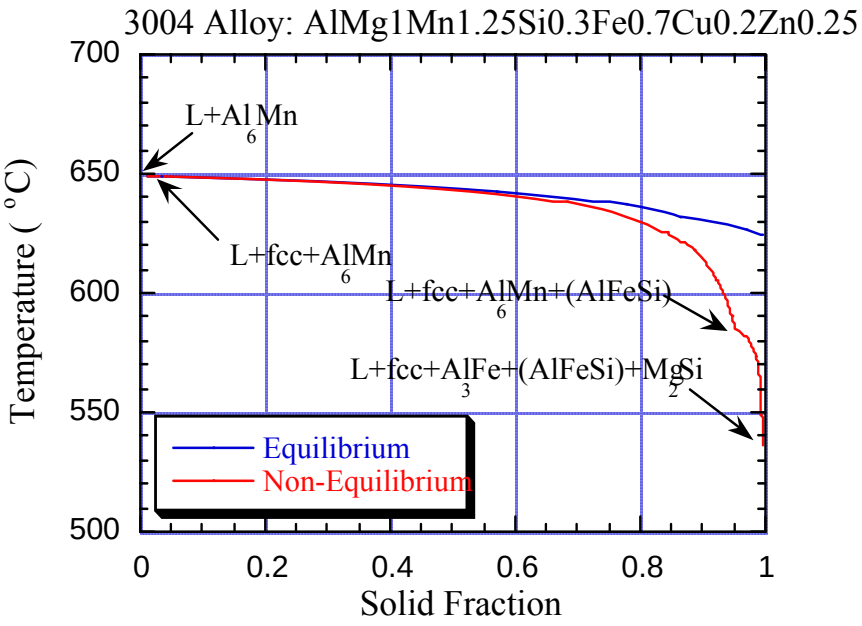
Temperature (°C)	0~350	300~500	500~600	550~650	630~710	700~770
Radiator length (inch)	5	4.75	4.52	4.08	3.89	3.81

Results of Coating Test

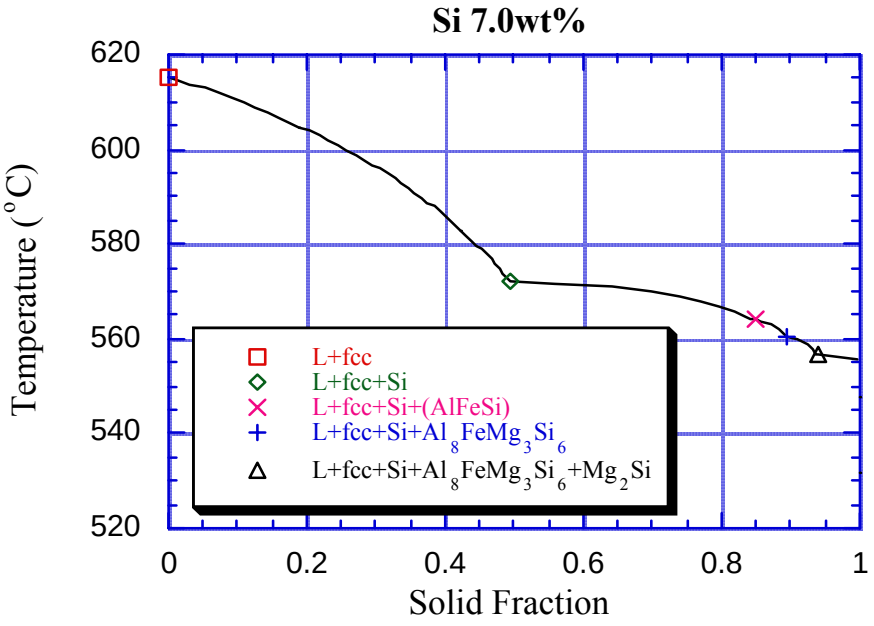
- Without coating, molten aluminum attacks the probe.
  - left: sample photo
  - right: microscopic structure
- Four types of coating have been tested
  - Graphite, Boron Nitride, thick oxide, and Z-Guard
- Z-Guard coating holds tightly on the Ti tube surface.
- TiN, TiC and other line compound coatings will be tested



The Temperature versus Solid Fraction Curves of Commercial Alloys Have Been Determined Using Thermodynamic Simulations



Aluminum 3004 alloy



Aluminum A356 alloy

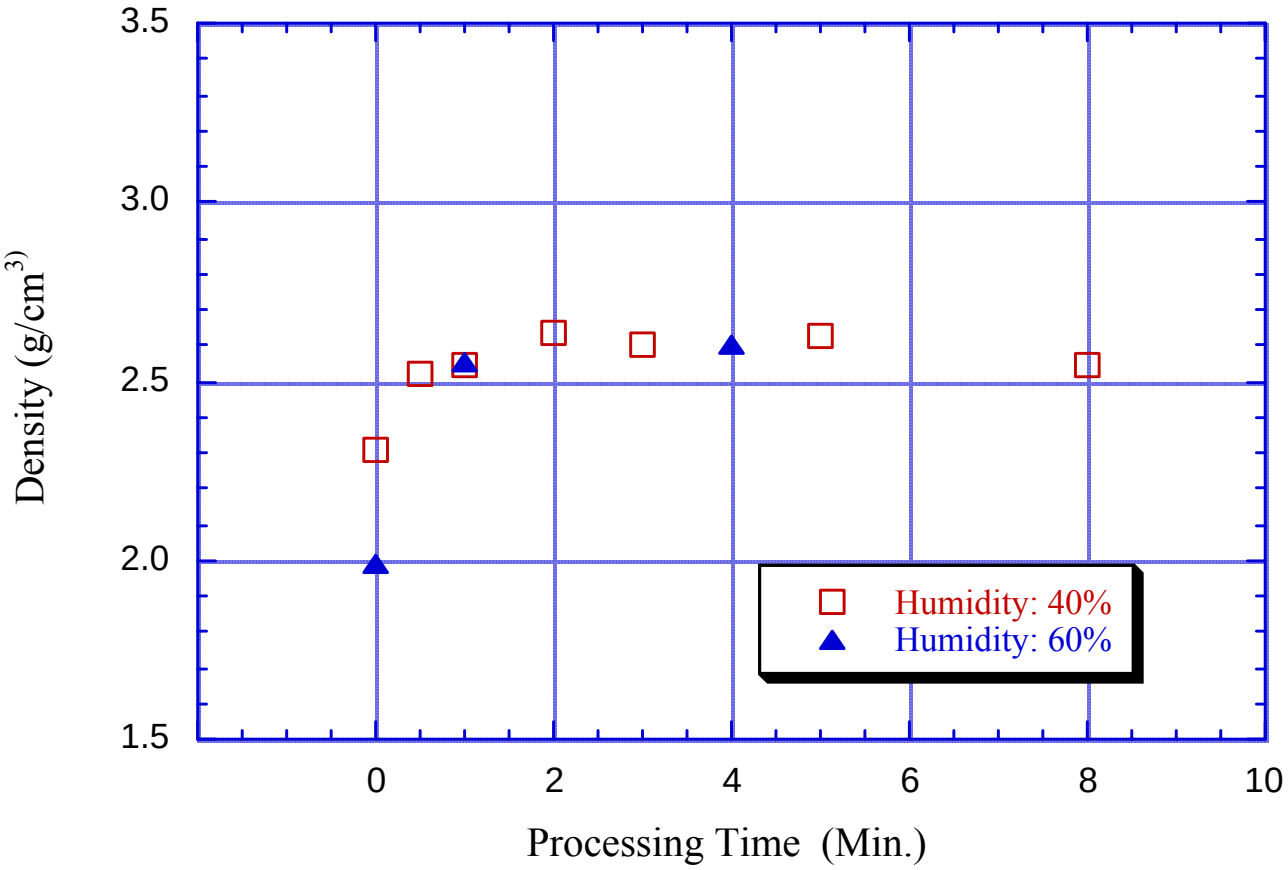
Experiments on Ultrasonic Degassing Have Been Completed

- **Vibration amplitude**: 30%
- **Humidity**: 40%
- **Temperature**: 740°C
- **Material: A356**
- Samples Were Solidified in the **RPT Unit.**

No vibration | 1 min | 5 min

The vacuum is set 28 inches Hg (pressure: 50 torr)

Degassing in Aluminum Melt Can Be Achieved in Just a Few Minutes



Experiments Have Been Carried out to Reduce Grain Size

- **Materials involved:** A356, 3004, Steel
- **Adjustable acoustic parameters:** Amplitude 40~100%
- **Frequency:** 20KHz, 100KHz~20MHz
- **Ways to process the melts:**
  - **Intermittent processing**

    Time and temperature are variables, i. e., 10 sec (650^{o}C, 645^{o}C, 640^{o}C, …, 570^{o}C); 20 sec (…); 40sec (…); …
  - **Isothermal treatment**

    Time and temperature are variables.

Experimental Procedure

- Isothermal treatment

  Apply acoustic power in the melt for a given amount of time at a set temperature, remove the acoustic horn, and cool the melt with two cooling rates.

- Intermittent processing

  Keep the radiator hot above the melt. When the next set temperature is reached, acoustic energy is applied for the same duration. Repeat until the specified temperature range has been explored.

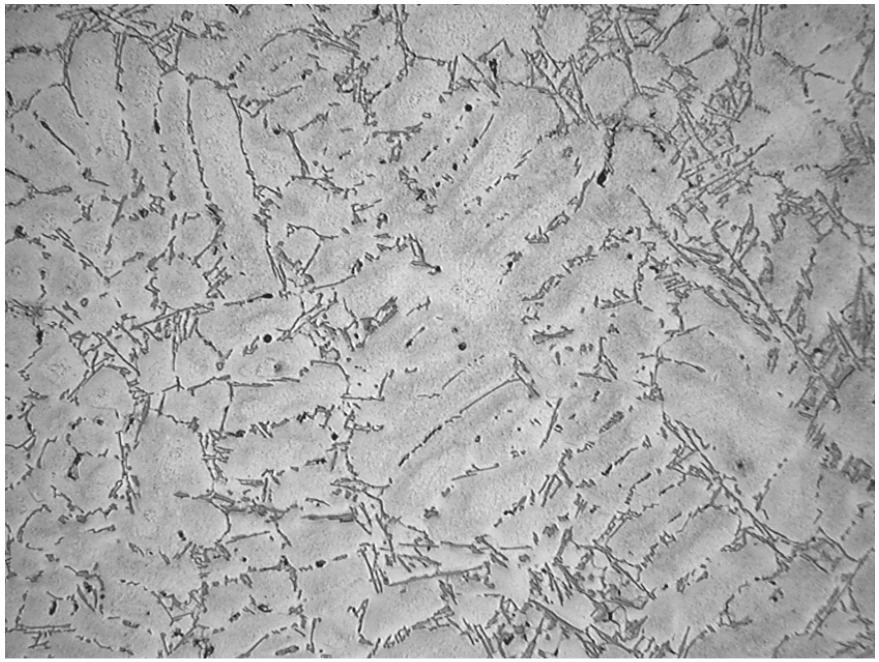
Globular Grains Have Been Obtained Using Ultrasonic Vibrations

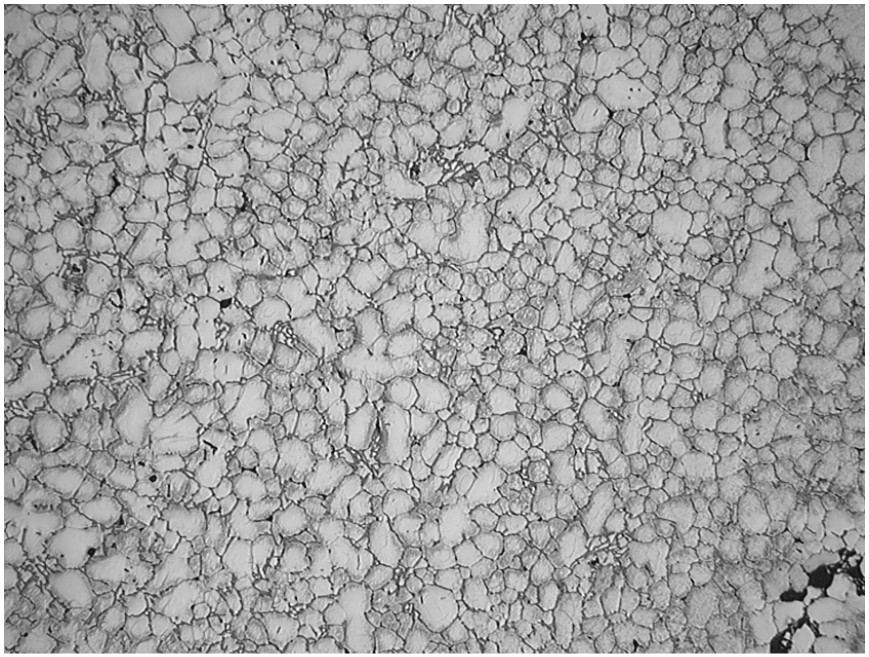
- Baseline (left)

No ultrasonic treatment, air cooled right after 560°C

- Intermittent treatment

Start ultrasonic treatment at 616°C for 10Sec, then repeat 600°C, 590°C,…, 560°C, air cooled right after 560°C

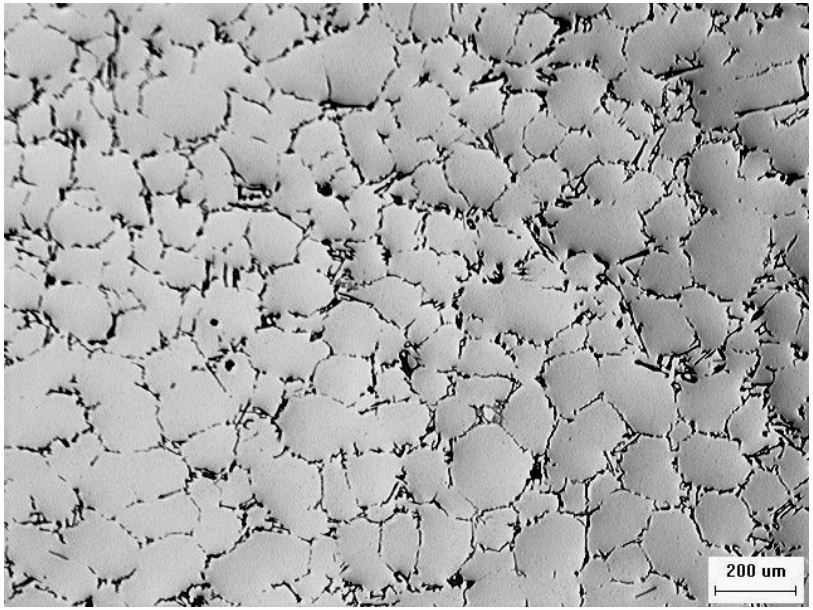




(continue)

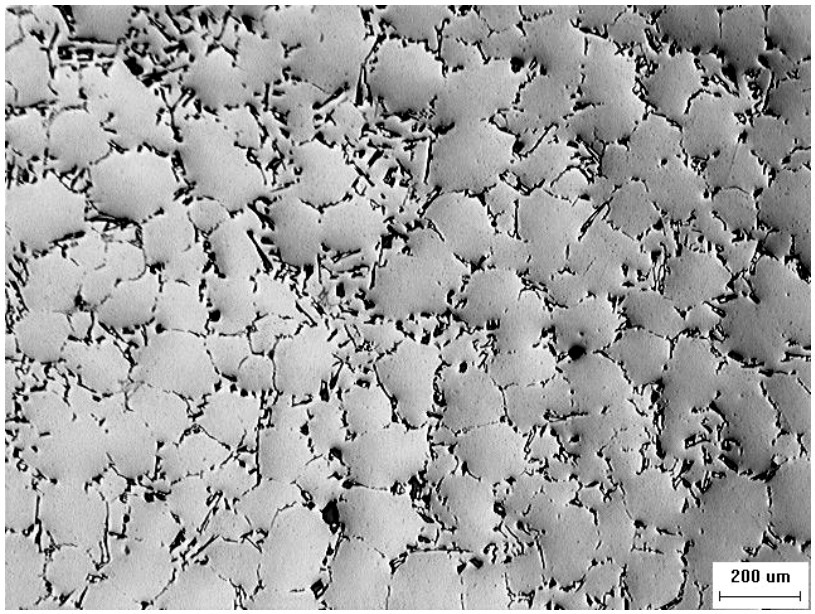
- Intermittent treatment

Start ultrasonic treatment at 614°C for 10Sec, then repeat at 610°C, 606°C,…, 574°C, air cooled right after 574°C



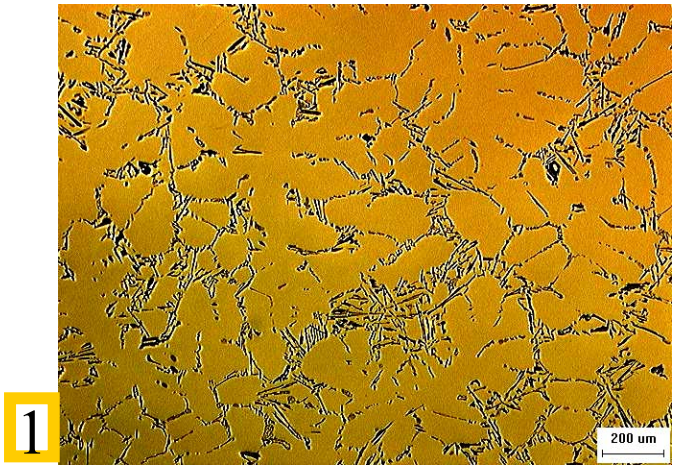
- Intermittent treatment

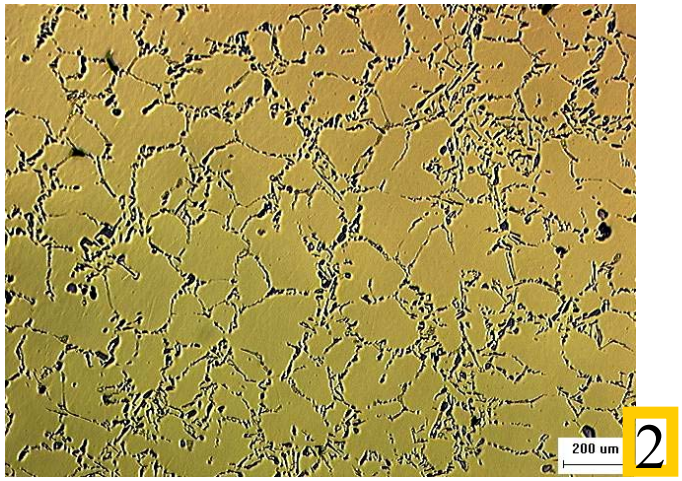
Start ultrasonic treatment at 614°C for 20Sec, then repeat 610°C, 606°C,…, 574°C, air cooled right after 574°C

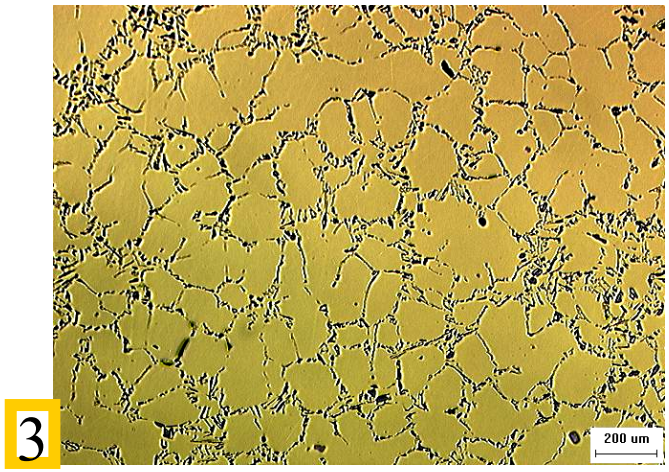


Grain Refinement Can Also Be Achieved Using Ultrasonic Vibration at isothermal Temperatures

1. Baseline, no ultrasound
2. Isothermal: 614°C, 20Sec
3. Isothermal: 610°C, 20Sec







Publications and Patents

- **Two publications in progress**
- **One patent application in progress**

Conclusions

- Ultrasonic energy has been successfully used for the degassing in aluminum melt
- Globular microstructure has been obtained using ultrasonic energy. The size of spherical grains is only about 300 micron, much smaller than those in specimens without using ultrasonic energy.

Future Work

- Ultrasonic grain refinement in steels
- Parametric studies of grain refinement using ultrasonic vibration in A356, 3004, 6061, and 6062, varying power density, amplitude, duration , and temperatures.
- Higher frequencies will be used to apply acoustic energy into the melt
- Modeling of the process will continue